Institute of Paper Science and Technology
Atlanta, Georgia

IPST Technical Paper Series Number 663

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July 1997

Submitted to
GATF World
Journal of the Graphic Arts Technical Foundation
Sewickley, PA

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Printing Characteristics of Uncoated Papers with Recycled Fibers: Color Gamut and Image Sharpness

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ABSTRACT

The printing characteristics in terms of color gamut and image sharpness achievable of uncoated papers with post consumer recycled fiber were examined. The color gamut was not found to be lower for papers with recycled fibers. Recycled fibers did not seem to impact image sharpness significantly. Instead, it is smoothness of the paper surfaces that impacted image sharpness as surface irregularities had a detrimental effect on ink transfer.

I. Introduction

As a whole, the printing industry is the largest consumer of paper products with shipments in the United States estimated in excess of 100 billion dollars in 1990[1]. Due to the importance of the printing industry to the paper industry, the paper maker needs to examine the trends as well as the requirements of the printing industry in order to produce papers suitable for printing. The suitability of a given grade of paper depends on the type of printing process being used and variations thereof.

Besides the technological advances, environmental factors have been a substantial driving force in the trends of the paper and printing industries. With public sentiment mounting to conserve our forests and reduce our landfills, papers using post consumer recycled fiber are seen as more eco-friendly and thus more attractive for the environmentally conscious public.

The amount of post consumer recycled fiber content in paper has been regulated by the federal government in recent years, with the states also following with similar regulations. The uncoated printing and writing paper grades purchased by the state and federal governments especially have been regulated. For example, these grades purchased by the federal government must contain a minimum of 25% post consumer recycled. This is most likely to be increased to 30% in the near future. Thus, with the increased use of recycled fiber in these papers necessitated by public sentiment and government regulations, it is essential to understand how these papers behave during printing with the offset lithography process in regard to image quality.

Offset lithography is a complex and variable process. The ultimate goal of the printer is to efficiently produce prints that are as close to the original as possible. A variety of physical and optical properties of paper contribute to the faithfulness of the reproductions. The main physical properties are surface strength, formation, water resistance, and smoothness. The optical properties are opacity, scattering and absorption coefficients, brightness and color of paper for color reproduction. Even so, the uniformity of these properties are especially important. Without uniformity of paper properties, the ability to reproduce quality prints will suffer accordingly[2,3].

So, how exactly do these paper properties affect the color gamut and the image sharpness? In traditional paper technology literature, there has been very little work done in these areas from the paper technologist point of view.

The color gamut is the range of colors which can be achieved in a given printing process with a given set of ink and paper. "Conventional wisdom" says that the largest gamut is achieved with a glossy, calendered, white, coated, wood-free paper [4]. In a recent study by Bristow[4], the color gamut achievable on newsprint was compared with that of coated paper.

He found that newsprint had a smaller gamut than coated paper in two-dimensional and three-dimensional representations of the CIELAB L*, a*, b* color space. Graphs of a* vs. b* were constructed for the additive and subtractive primary colors that were printed which contained the chromaticity data. Connecting the data points by straight lines gave a rough representation of the range of colors that can be achieved.

He concluded that much work needs to be done to obtain basic knowledge of the factors determining the color gamut achievable on paper. However, no attempt was made to explain why newsprint had a smaller gamut then coated paper substrates.

In color printing, faithful color reproduction is not the only factor affecting quality. The image produced must also be sharp to the viewer. Image sharpness is widely accepted as important in evaluating the quality of prints. Many researchers [5-9] in the past have tried to find a relationship between an objective index and the sensation of sharpness. Stanton and Warner [10] developed the GATF Frequency Modulated Acutance Guide (FM Target) which provides a means of measuring an index of acutance that would correlate with the sensation of image sharpness. Initial results have showed promise and more improvement for ink-on-paper samples remains to be done.

These works, however, also failed to examine image sharpness from the paper technologist point to view as to why images printed on a paper are seen to be sharper then that from another paper. With the recent trend of the increased use of recycled fibers in printing and writing papers, there is an obvious need to understand how paper properties, and especially papers containing recycled fibers, affect the color gamut and image sharpness achievable to better gauge the printing capability of the papers.

This literature review showed that very little has been done to characterize the printing behavior of papers with recycled fibers. And based on what little was known, the following hypothesis was proposed:

Post consumer recycled fiber content will decrease the color gamut achievable while having no significant effect on the image sharpness of uncoated papers printed by offset lithography.

For this project we wanted to accomplish a few things in addition to testing the hypothesis. First, we wanted to determine relationships between properties of paper and color gamut and image sharpness. Second, we wanted to establish whether it was the brightness or the recycled fiber that impacts color gamut and image sharpness to a greater extent. And finally, we wanted to make recommendations based on our results to the paper and printing industries concerning the use of post consumer recycled fiber in printing papers. These four issues were the main objectives of this project.

II. Experimental Procedures

To realize these objectives, five papers were used: two commercial uncoated papers and three laboratory made papers. The properties of these five papers were characterized. These papers were printed and analyzed at GATF for the color gamut and image sharpness information. The data were compared between the papers to determine trends.

The two commercial papers, A and B, were supposedly two papers with the same furnish and brightness except that B also has 25% post consumer recycled fiber. We made the other three papers at IPST in Atlanta prior to the summer of 1996. One consisted of all virgin pulp, one each with 25% and 40% post consumer recycled fiber. We used sorted office waste from the recycled bins at the Institute as the recycled fiber content. This pulp was not deinked or washed to make a worst case scenario.

During the summer of 1996, printing runs were conducted at GATF using an AM Multi 1650 MC duplicator press. The target densities were such that the ink film thickness for the process inks, CMYK, were held constant to reduce non-experimental parameters and to see the effects of the papers. The densities were calculated using the Tollenar-Ernst equation from IGT Printability Tester strips. This is the test target used; it consisted of two solid bars, a 50% tint and four GATF FM Acutance Guides. The Acutance Guides were used to calculate the image sharpness of line pairs ranging from a frequency of 400 to 1400 cycles per inch. Photomicrographs were also taken of the line pairs to compare the sharpness of the line edges visually. The data from the printing runs mainly consists of density readings from an X-Rite 418 Densitometer and CIELAB L*, a*, b* values from an X-Rite 938 Spectrodensitometer.

The paper properties identified earlier were characterized using standard TAPPI testing methods. The color gamut and image sharpness data were compared with the paper properties to determine their relationships.

III. Discussion of Results

Color Gamut

From the discussion above, the information on color gamut achievable can be easily obtained from the printed sheets. Measurements made with spectrophotometers gave the L*, a* and b* values for the prints of each of the colors. However, it would be too time consuming to examine all the intermediary colors between the primaries. For this reason, it would be appropriate to obtain an estimate of the color gamut by simply connecting the data points with straight lines as done by Bristow. However, we have to keep in mind that we really do not have a clear picture of what is happening at the intermediary colors.

The color gamut of the papers containing recycled fibers seemed to have a lower gamut than the two papers with virgin fibers (Figures 1 & 2). Here the gamut is simply the area of the triangle enclosed by the three data points representing the a* and b* values of the cyan, magenta and yellow inks. Looking just at the data points, they show that there is indeed a smaller color gamut on the papers with the use of recycled fibers. Table 1 shows exactly how much the gamut differ by. The differences, however, are not significant at the 95% level.

The 40% is an anomaly that can be explained. Looking at Fig. 2, it is apparent that while one of the data points was basically the same, the other two were different for the three papers. These two data points represent the a* and b* values for magenta and yellow. The most possible cause that comes to mind is the density variation of the inks.

Due to the variation of the many factors present during printing, it is natural to assume there will be density variations within a press trial that could contribute to the variations in L*, a* and b* values. The results are tabulated in Table 2 along with the average densities for each paper and color. It is clear that there were indeed density variations that contributed to the difference in L*, a* and b* values.

Statistical tests of significance were performed to help further explain this anomaly. T-test at the 95% confidence level were conducted to determine whether the mean densities of the lab-made papers were the same. For cyan, Virgin and 25% Recycled were the same but the 40% Recycled was not. For both magenta and yellow, both the 25% and 40% Recycled papers had different densities than the Virgin.

When the gamut area (normalized to the gamut area of A) was plotted against the brightness of the papers (Fig. 3), an expected trend emerges. The basic trend is that the brighter the paper the higher the color gamut . This agrees with the "conventional wisdom" that says the largest gamut is achieved with the brighter paper. Furthermore, the normalized gamut area was plotted against the percent recycled (Fig. 4). An interesting question rises: Whether the brightness of the papers or the percent recycled in the paper affects the color gamut more? There was a similar drop in the gamut area between the two papers with all virgin fibers (A and Virgin) to the two papers with 25% recycled fiber (B and 25% Recycled). This was indicative of the brightness difference between the all virgin fiber paper and the ones with recycled fibers (Table 3).

Papers A and B were supposed to have the same brightness, which would have made this comparison easier. Even so, Figs. 3 and 4 show that the recycled percentage does not seem to have affected the color gamut area significantly. The R^2 values of 0.56 and 0.05 for the two graphs gives further support of this. Thus, it is the brightness of the paper that impacts color gamut more rather than anything inherent in the recycled fibers. More research needs to be done in this area to further validate this claim that the brightness affects the color gamut more than recycled fiber content.

Image Sharpness

As for the analysis of image sharpness, the principle behind the FM Acutance Guide is reasonable. However, it does not seem to work well on paper substrates as mentioned in the literature review due to light scatter. On the prints, 600-800 cycles per inch (cpi) is the highest frequency resolved under the microscope. The acutance index calculated from density readings did not correlate well with the visual examination of the photomicrographs (Table 4). The visual examination of the Acutance Guide was a subjective evaluation of the line sharpness of the photomicrographs. In fact, the numbers did not make sense at all; lower frequencies had high Acutance Index and higher frequencies had low index indicating that the higher frequencies were sharper than the lower frequencies. This was simply not true; in fact, the higher frequencies (>800) were not even resolved.

Even so, the light scattering effects of paper can be quantified and this could lead to a way of incorporating the light scattering effects of paper into the calculations for the acutance index that will give better results. If this is possible, it could find wide spread use in the graphic arts industry. For example, physical dot gain of halftone reproductions can be measured. This might be possible because light scattering effects of paper contributes to optical dot gain. Therefore, the measured dot gain will only refer to the physical growth of the halftone dot. However, due to the time limitations of this project, it was not feasible to find a way to take the light scattering effects of paper into account when calculating the acutance index.

Visual examination of typical photomicrographs showed very little difference in sharpness between the papers. On occasion, there will be photomicrographs that show differently. The fiber surface, which can also be seen, shows that the ones that are sharper are usually the ones with less surface irregularities (Fig. 5). The surface irregularities affect the transfer of ink from the blanket to the paper, which gave more broken lines. Consequently, surface irregularities contribute to lines that are less sharp.

Paper Properties

The papers used in this project were also characterized to determine relationships between properties of paper and color gamut and image sharpness. Tables 5 and 6 list the average values of the paper properties that were characterized.

The data suggests that within a set of papers (commercially made and lab-made papers), the papers had similar values for the physical properties. The difference in the trends of the optical properties such as scattering coefficient, s, is probably due to the presence of ink particles which was not washed out of the recycled fraction used to make the lab-made papers.

III. Summary and Recommendations

The color gamut does not seem to be significantly affected with the addition of recycled fiber. The mean values are precise, but the spread of the data points are within two standard deviations (error bars on Figs. 1 & 2). Also, the difference in the means could be due to instrumental error of the densitometer. The image sharpness was not affected by the presence of recycled fibers per se, rather it was the smoothness that has a greater impact on sharpness.

Based on these results, printers can rest assured that using papers with post consumer recycled fiber will not compromise the quality of the print job in terms of color gamut and image sharpness. As stated earlier, the color gamut is probably affected more by the brightness and it is the smoothness that will affect the sharpness. Given what we know about recycled fibers from research spurred on by the recent trend towards using more recycled fibers, paper makers are utilizing more and more the proper processing techniques to produce recycled papers that compete with all-virgin fiber papers.

As for the paper maker, a combination of paper properties required in the offset process as well as the effects of recycling on the fibers present some problems in making suitable offset papers with recycled fibers. These papers must possess adequate surface strength, smoothness, water resistance, and have good formation, high opacity, brightness and whiteness. Paper makers must utilize the necessary processing techniques to ensure this.

We recommend the following further research:

1. Further work needs to be done to substantiate our assertion that it is the brightness that affects color gamut rather than anything inherent in the recycled fibers themselves.
2. How the light scattering effects of paper influences densitometric readings such as dot gain should be investigated so that the GATF FM Acutance Guide will provide a more meaningful acutance index.
3. Further research is needed to examine if color gamut is decreased at all by the use of recycled fibers.

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IV. Acknowledgment

The authors thank the Institute of Paper Science and Technology and the Graphic Arts Technical Foundation for their support and especially the generous financial funding provided by the Society of Fellows Visiting Scientist Program during the summer of 1996.

Figure 1. Color Gamut of Commercial Papers (diamond-A, square-B). Error bars are drawn to 2 standard deviations.

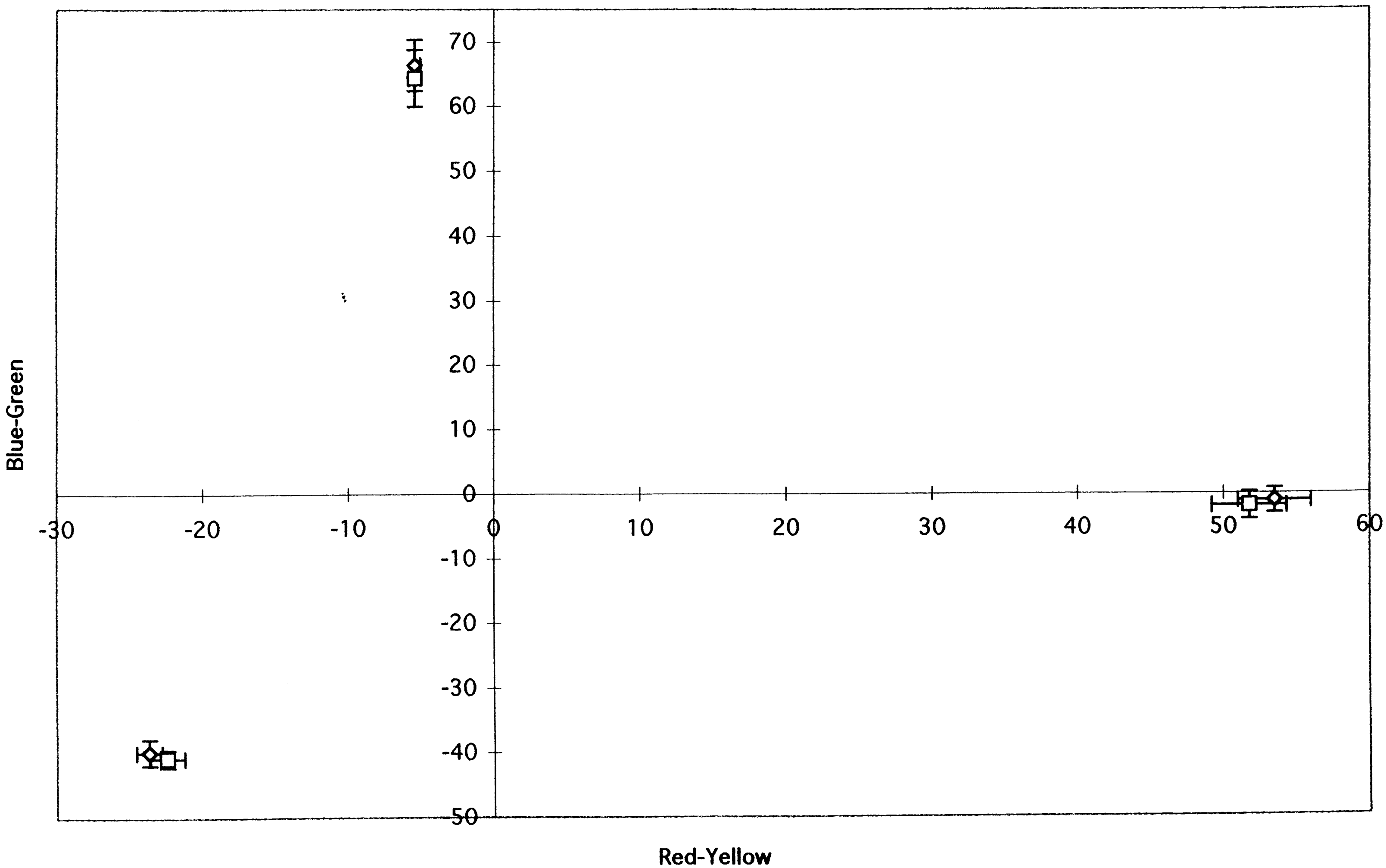


Figure 2. Color Gamut of Lab-made Papers (diamond-virgin, square-25% Recycled, circle-40% Recycled). Error bars drawn to two standard deviations.

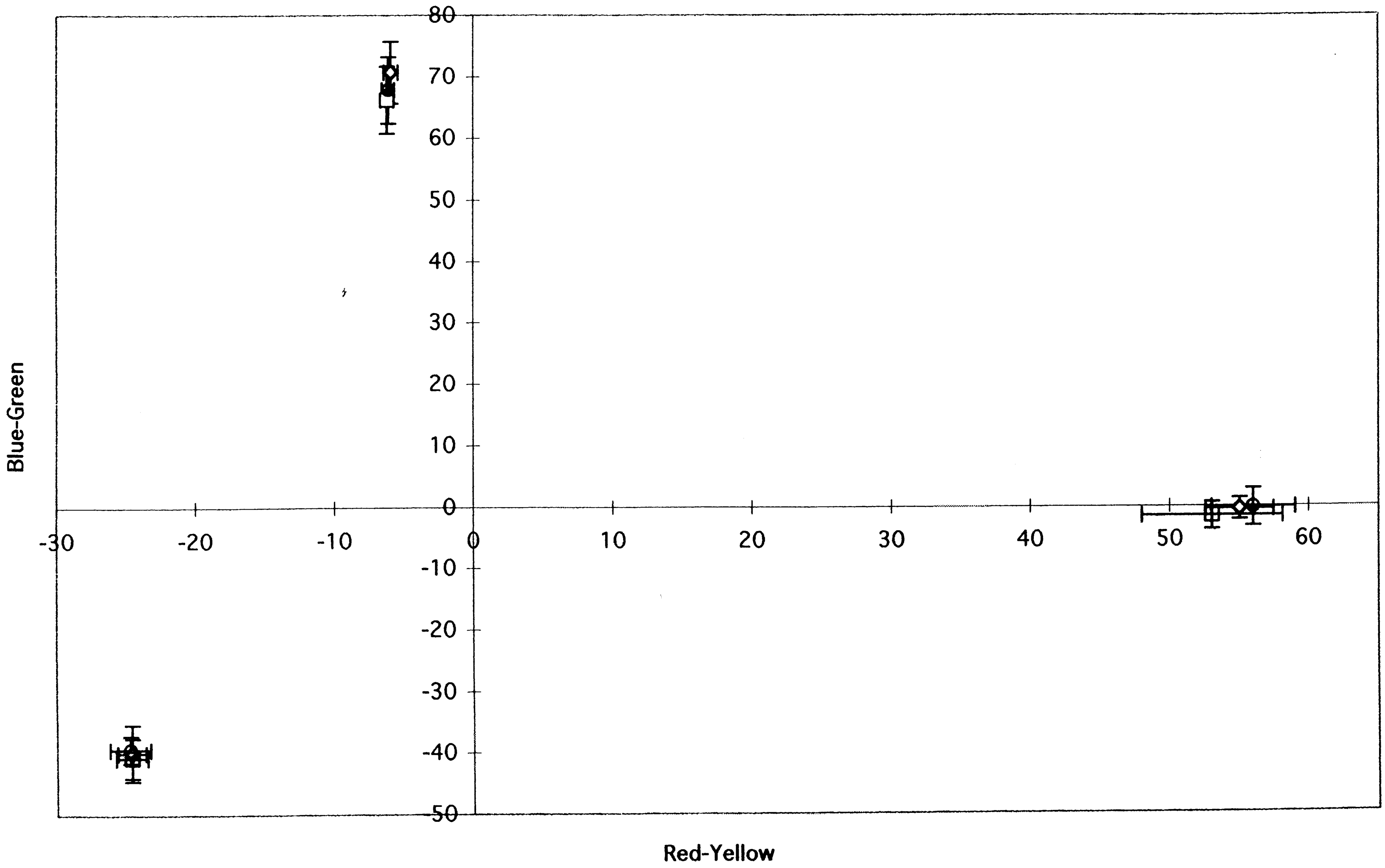


Figure 3. Brightness Effects on Color Gamut Area

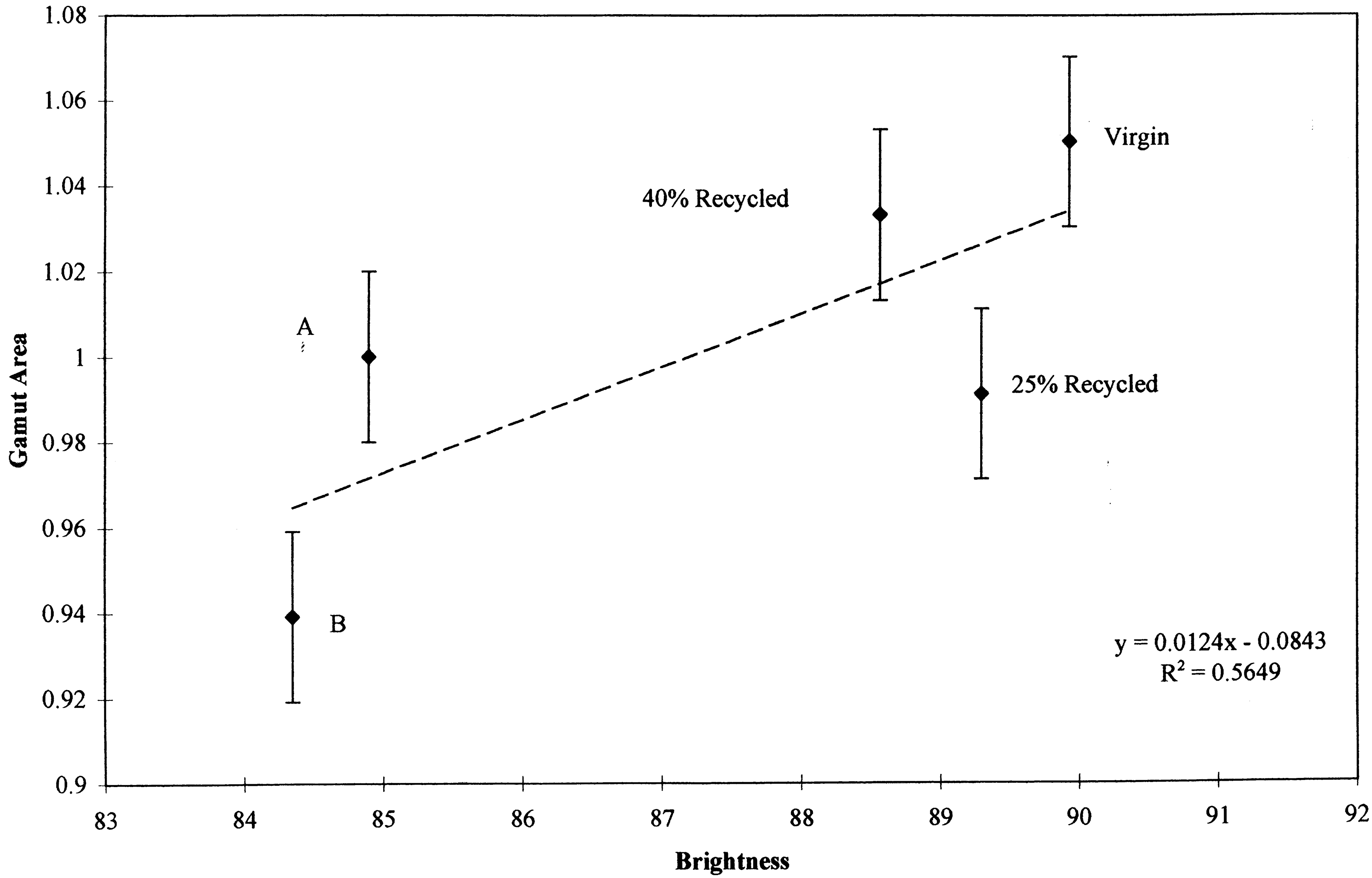
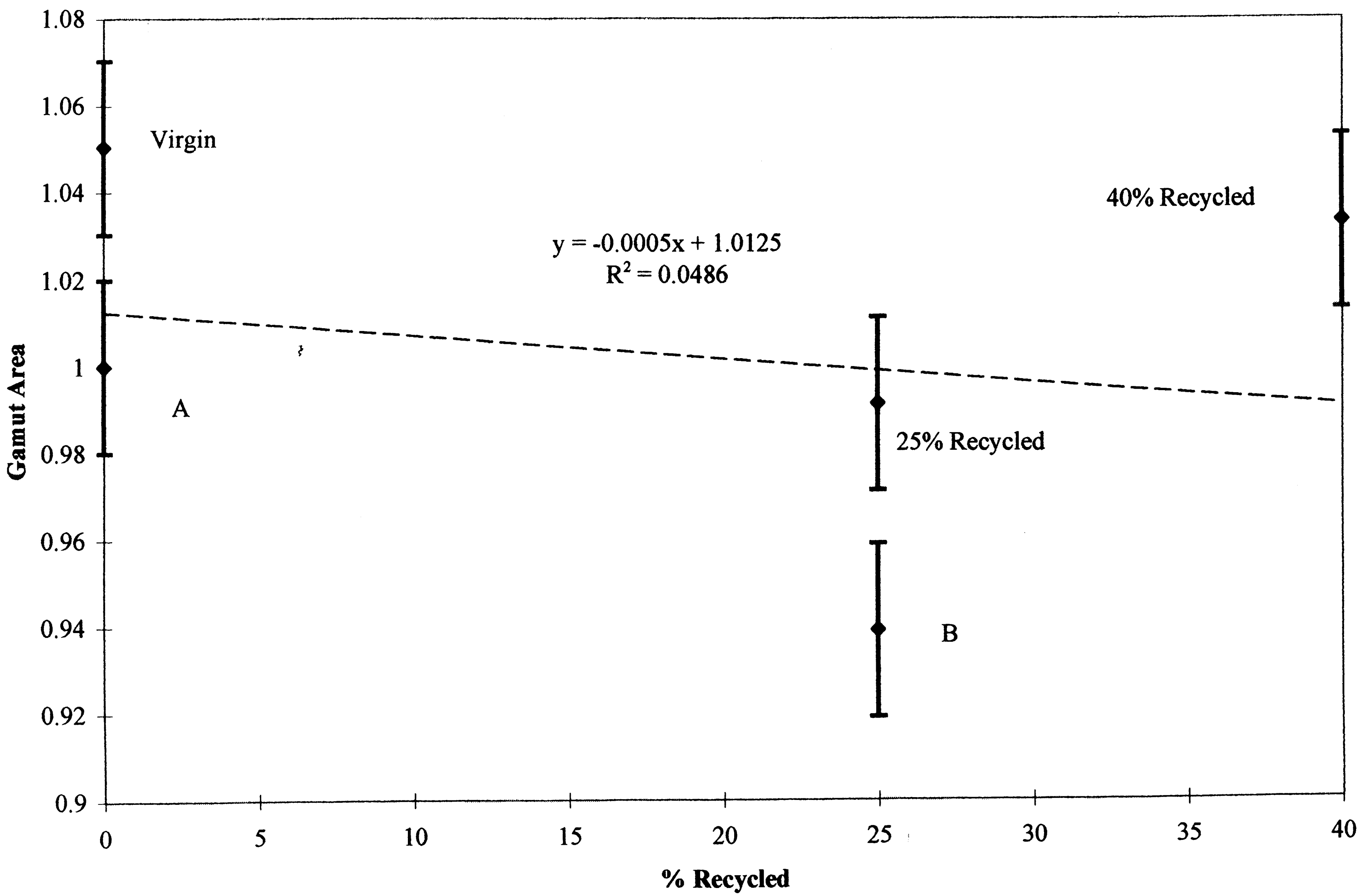


Figure 4: Effect of Recycled Fiber on Color Gamut



Photomicrographs of Lab Made Papers (all 400 cycles per inch at 100X magnification)

Virgin | 25% Recycled | 40% Recycled

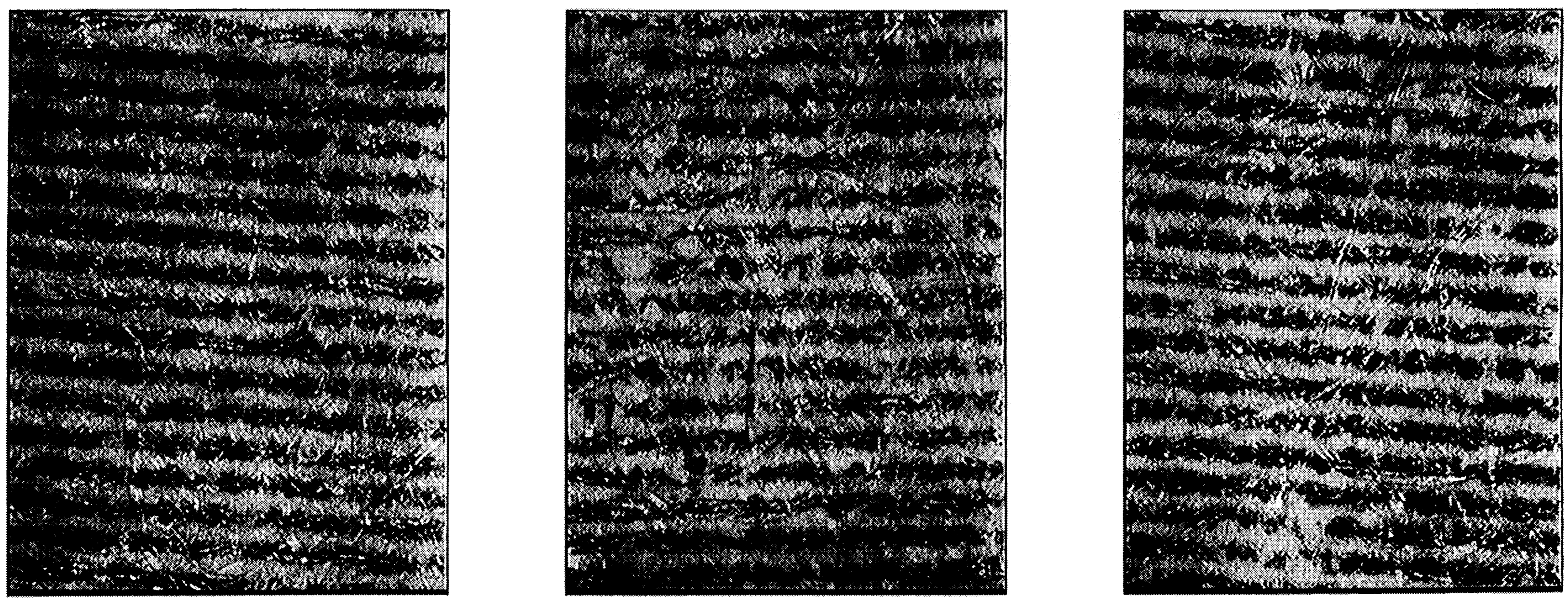


Figure 5. Photomicrographs showing the importance of surface irregularities.

Table 1: Color gamut area of the papers in square inches		
Paper	Gamut Area	Normalized to A
A	13.464	1
B	12.644	0.9390969
Virgin	14.141	1.0502822
25% Recycled	13.346	0.9912359
40% Recycled	13.910	1.0331254

Table 2: Density and L* a* b* data from press runs						
Trial press run standard deviation: 0.03934						
	Paper	Density	SD	L*	a*	b*
Cyan						
	A	0.96	0.0259	59.0263	-23.69	-39.667
	B	0.997	0.023	56.433	-22.332	-40.608
	virgin	0.972	0.0319	60.5314	-24.613	-39.879
	25% Recycled	0.969	0.0346	59.2781	-24.602	-40.729
	40% Recycled	0.934	0.0262	61.4838	-24.73	-39.301
Magenta						
	A	0.929	0.0184	56.9747	54.9816	-1.1008
	B	0.909	0.0294	56.2391	52.0273	-1.6636
	virgin	0.921	0.0208	56.6619	54.8228	-0.4992
	25% Recycled	0.915	0.027	57.2429	53.0929	-1.81
	40% Recycled	0.938	0.0179	55.7544	56.0306	-0.2014
Yellow						
	A	0.779	0.0202	86.4498	-5.4524	66.2396
	B	0.774	0.0193	86.2423	-5.3942	64.8142
	virgin	0.777	0.0198	89.3497	-5.9186	70.69
	25% Recycled	0.736	0.0202	88.7167	-6.1911	66.1947
	40% Recycled	0.744	0.0232	89.0794	-6.1072	67.8053
Black						
	A	0.997	0.0206	38.6649	1.07995	1.54263
	B	0.994	0.0208	38.8363	0.86014	1.32299
	virgin	1.003	0.0256	38.1994	0.49528	1.35361
	25% Recycled	0.975	0.0289	40.29	0.42139	1.39306
	40% Recycled	1.005	0.0212	38.3914	0.48472	1.21889

Target densities:			
Cyan	.966	Yellow	.822
Magenta	.924	Black	1.006

Overall press run data:		
Color	Average Density	SD
Cyan	0.969	0.0326
Magenta	0.920	0.0258
Yellow	0.773	0.0226
Black	0.995	0.0218

Table 3: Brightness	
Paper	Brightness
A	84.9
B	84.35
Virgin	89.93
25% Recycled	89.3
40% Recycled	88.57

Table 4: Calculated Acutance Index					
cpi	A	B	Virgin	25% Recycled	40% Recycled
400	1.96	1.95	2.06	1.92	2.1
600	1.84	1.85	1.91	1.78	1.93
800	1.61	1.6	1.66	1.56	1.68
1000	1.38	1.37	1.41	1.37	1.41
1200	0.99	0.99	0.99	0.98	0.99

Table 5: Physical Properties of the Papers						
Paper	Basis Wt, g/m2	PPS side a	PPS side b	Wax-Pick #	HST, sec	Formation Index
A	77.1	5.385	5.254	7	183	8.075
B	77.7	6.255	5.717	6.5	166	9.075
Virgin	77.8	4.33	3.33	7	237	3.545
25% Recycled	75.3	4.257	3.26	6	216	3.52
40% Recycled	79.0	4.059	3.048	5	204	2.945

Table 6: Optical Properties of the Papers										
Paper	R(o)	R(inf)	Opacity	a	b	X	sW	s	kW	k
A	78	84.9	91.81	1.013	0.164	1.639	4.318	55.99	0.058	0.752
B	77.2	84.4	91.46	1.015	0.171	1.648	4.128	53.14	0.06	0.772
Virgin	83.5	89.9	92.81	1.006	0.106	1.81	5.852	74.31	0.033	0.419
25% Recycled	83.7	89.3	93.74	1.006	0.113	1.659	6.154	82.31	0.0395	0.531
40% Recycled	85.1	88.6	96.09	1.007	0.122	1.379	7.582	94.76	0.056	0.7